

Broadband Adaptive Beamforming

Motion Mitigation in the Littoral Environment by Frequency Averaging

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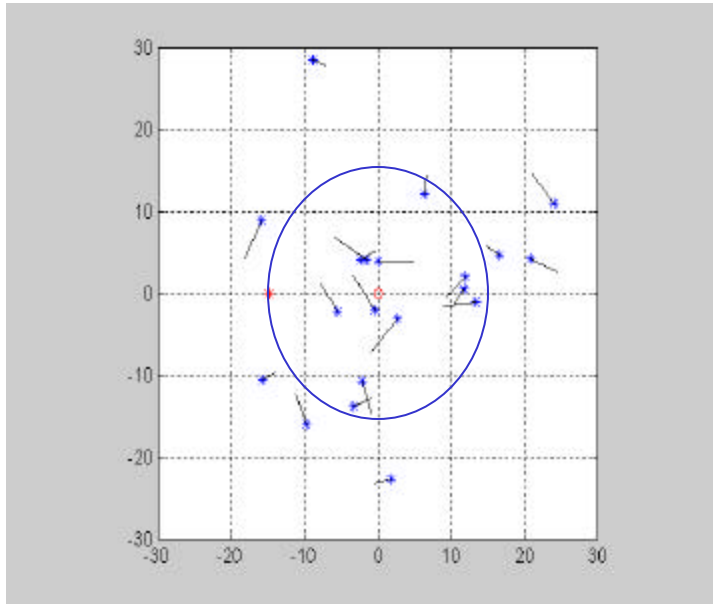
Single Wavenumber Adaptive Processing

SWAP Improves ABF performance vs dynamics

- Increases degrees of freedom
 - Improves convergence of covariance matrix
 - Exploits vertical arrival structure
 - Exploits broadband signature
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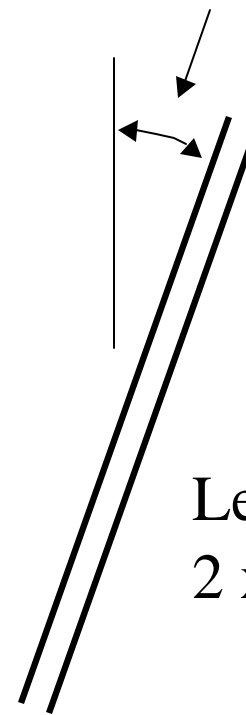
200 m Twin Line Simulation

188 - 200 Hz



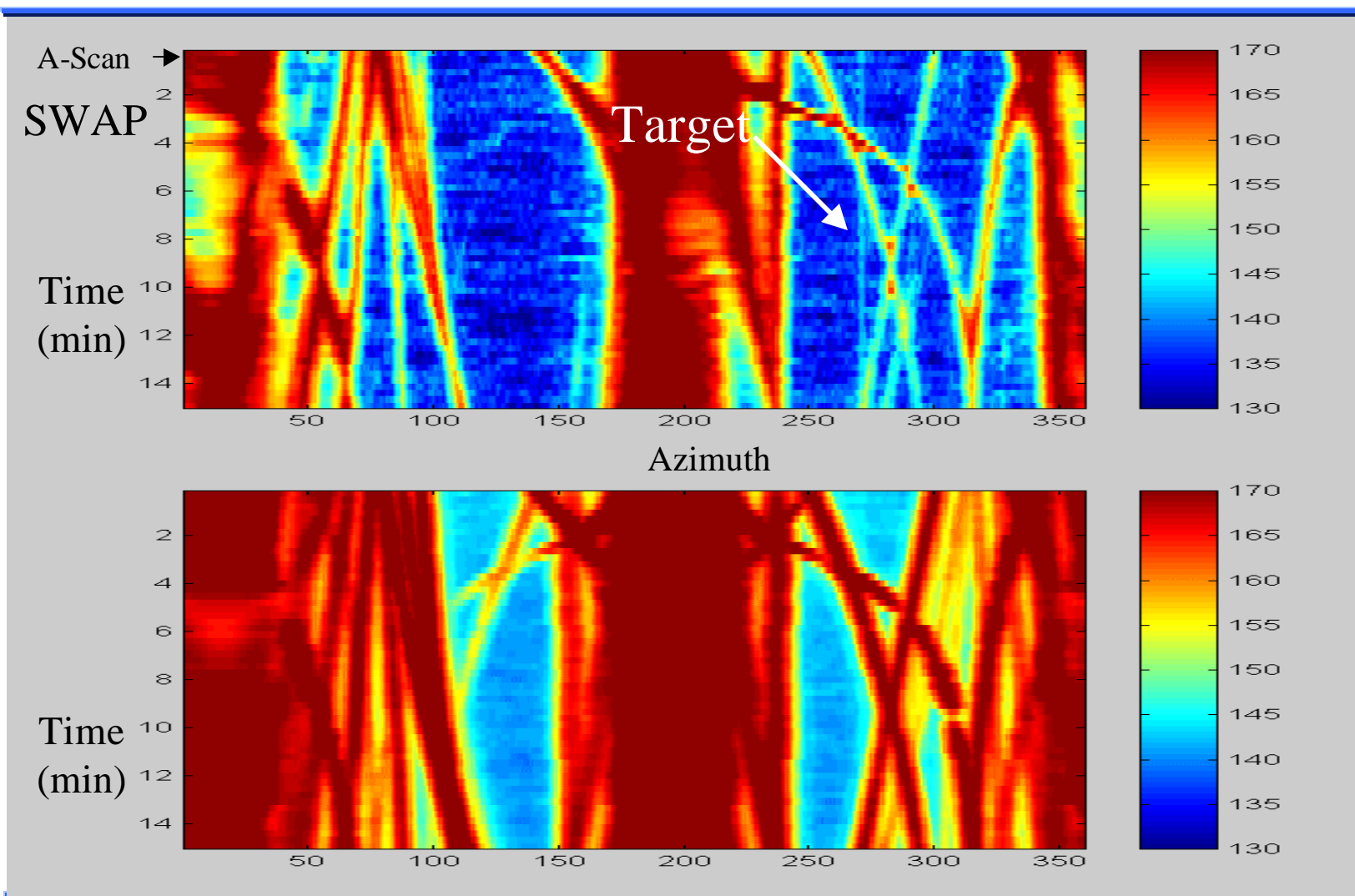
Average phone level 115 dB
Ambient white noise 65 dB
Average TL at 15 km 64 dB

Heading 15 degrees



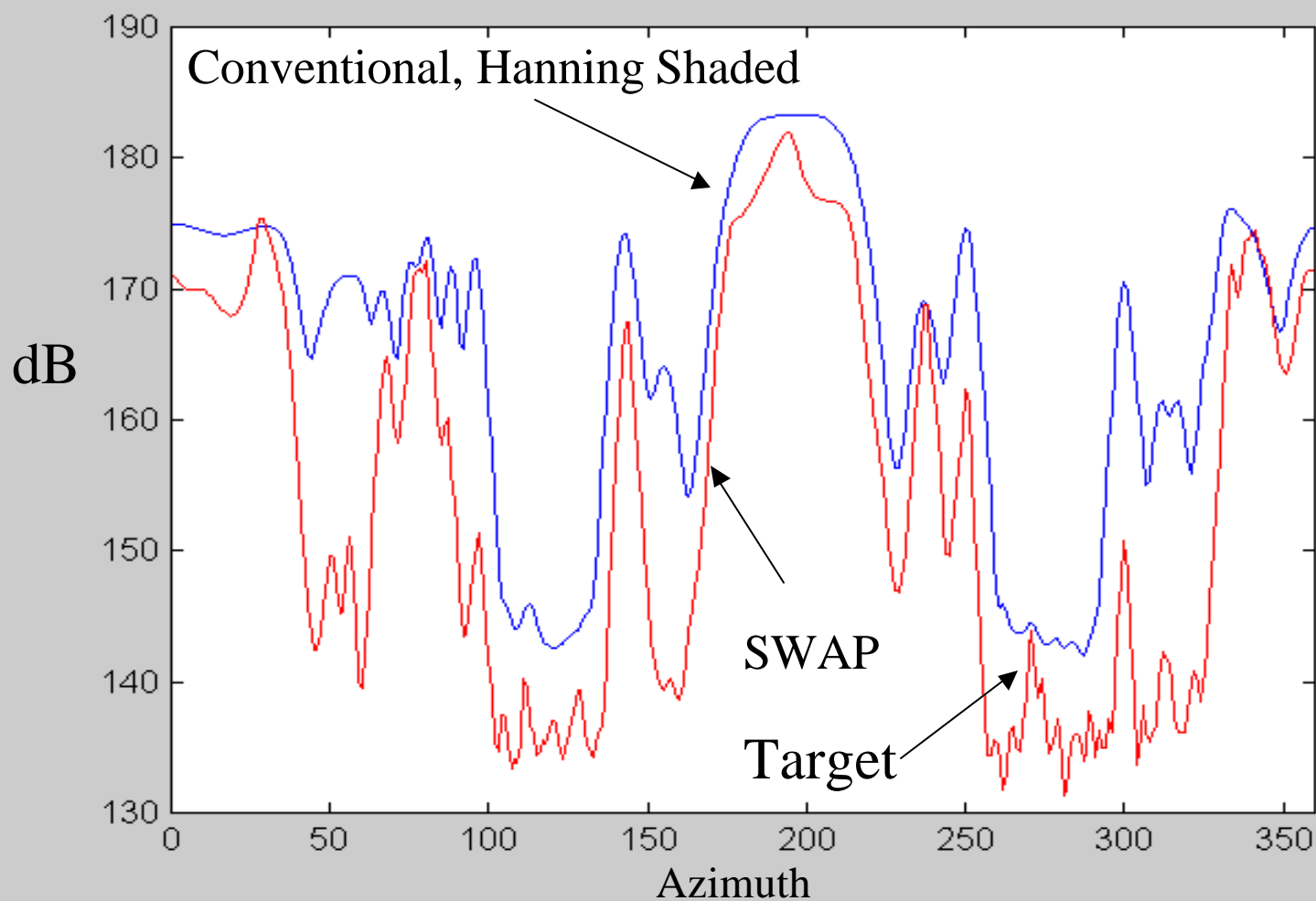
Length 200 m
2 x 65 phones

SWAP vs Conventional BTR



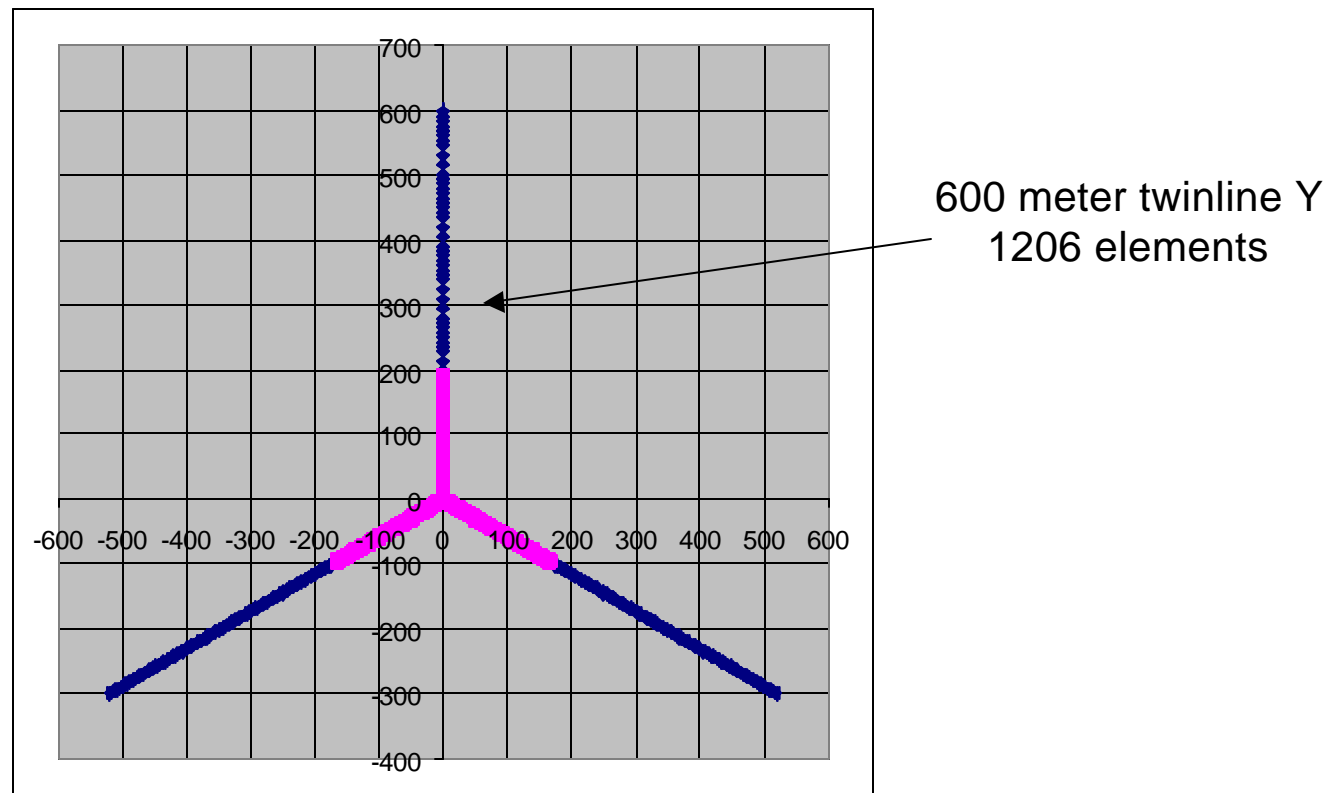
Conventional, Hanning Shaded

A-Scan at $T = 16$ sec



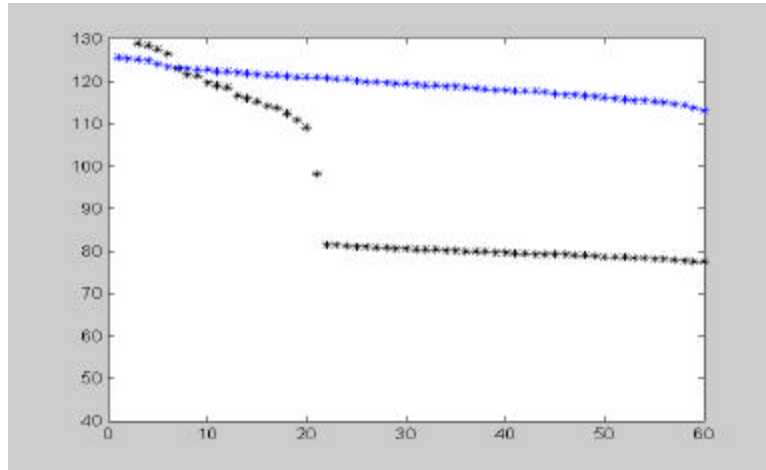
Large Aperture Example

Ocean Acoustic Observatory Study

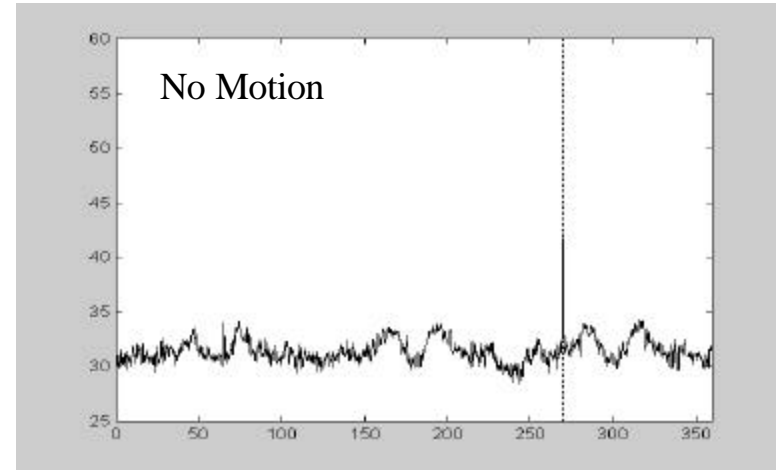


Ship Motion Causes Smearing

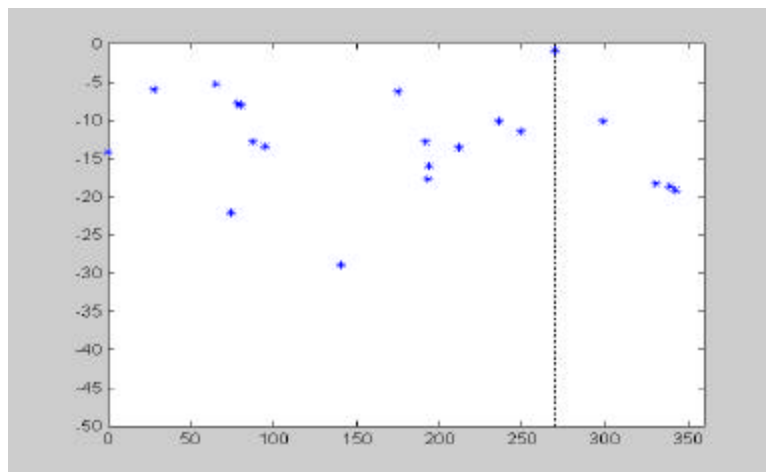
Eigenvalues, No Motion, Motion



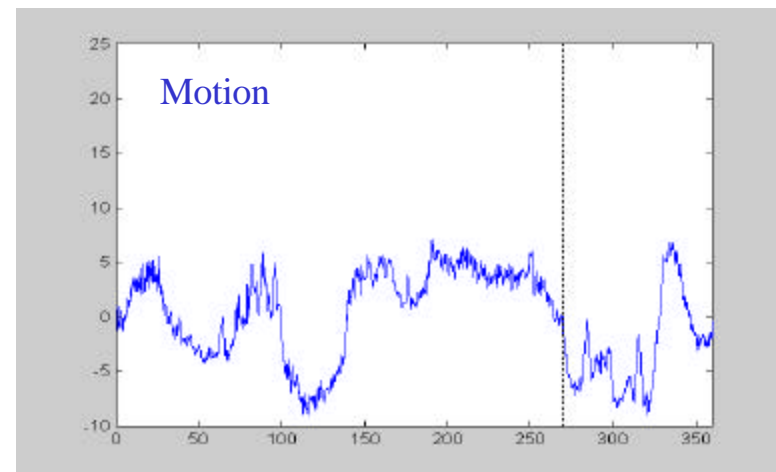
ABF Response at R = 15 km, Z = 100 m



Mismatch R = 15 km, Z = 100 m



ABF Response at R = 15 km, Z = 100 m

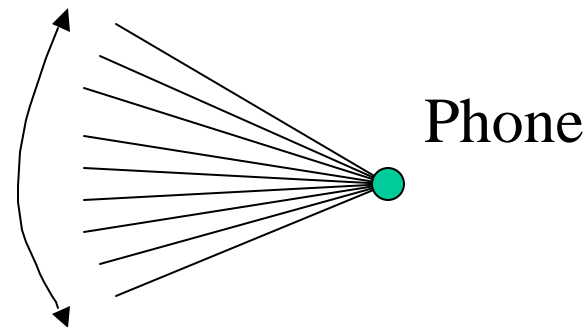


Use the Environment

SWAP Exploits Special Property of Shallow Water Propagation

Signals from each source
arrive in a continuous fan
of angles

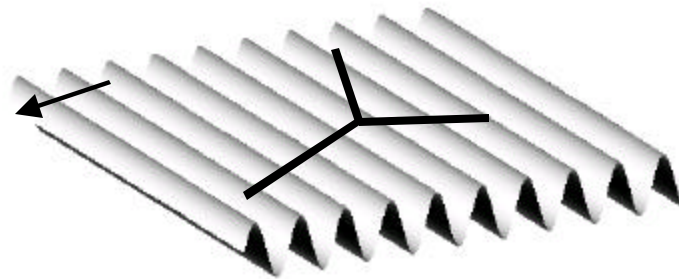
([-20, 20] degrees for OAO)



Bottom

SWAP Signal Model

- Range-focused plane wave replica
- Vertical arrival angle ϕ is free parameter
- Choose ϕ so horizontal wavenumber is constant



$$\exp (2 \pi i [f \cos(\phi)] (\cos(\theta), \sin(\theta)) \cdot (x_j, y_j))$$

↑
Horizontal wavenumber = k_0 , ϕ in $[0, 20]$ degrees

Example at 200 Hz

$$f \cos(\phi) = 200$$

The same plane wave replica:

$$\exp(2 \pi i [f \cos(\phi)] (\cos(\theta), \sin(\theta)) \cdot (x_j, y_j))$$

is valid over the frequency range [188 Hz, 200 Hz]

At 200 Hz, $\phi = 0$ degrees

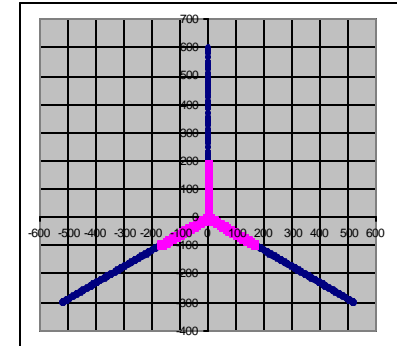
At 188 Hz, $\phi = 20$ degrees

Example: 600 m Twinline Y

Take 128 seconds of data from each phone

Fourier transform

Frequency resolution 1/128 Hz



12 x 128 = 1536 frequencies in [188, 200] Hz band

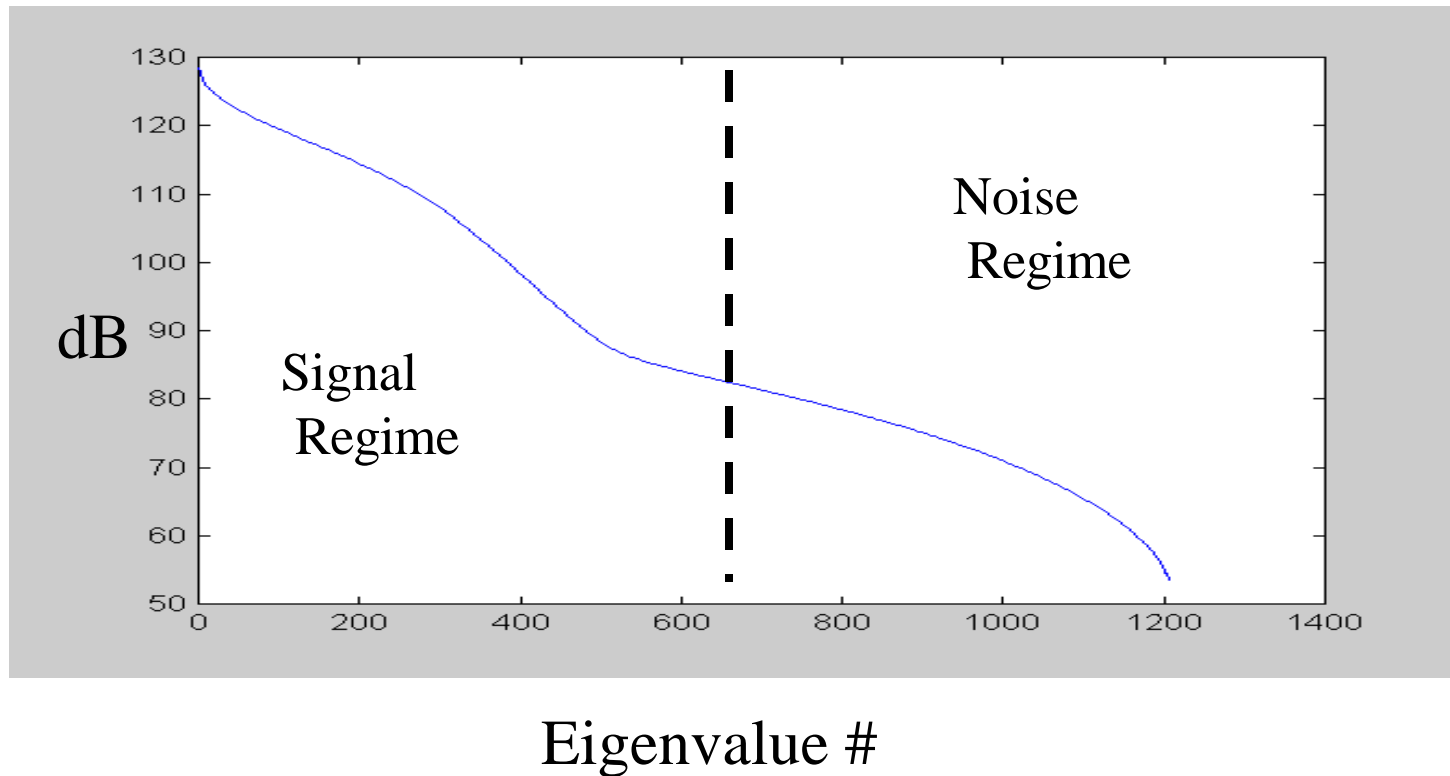
$$\text{BF}_{\text{Output}} = \sum_{j=1, 1536} | w_0^H \cdot \text{Data}(f_j) |^2$$

$$= w_0^H \cdot \left[\sum_{j=1, 1536} \text{Data}(f_j) \text{Data}(f_j)^H \right] \cdot w_0$$

←
Covariance Matrix, R

Spectrum of R Matrix

Form R_S by zeroing out noise eigenvalues



SWAP Algorithm

Single Wavenumber Adaptive Processing

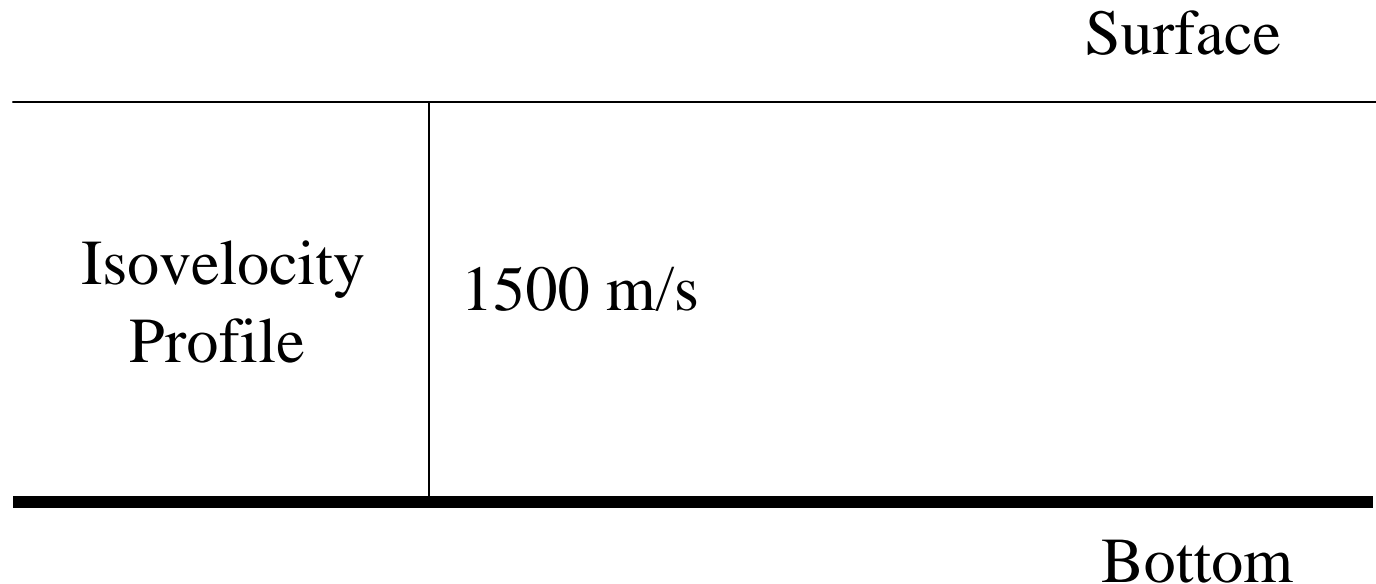
$$[w_0^H \cdot R^{-1} \cdot R_S \cdot R^{-1} \cdot w_0]$$

$$[w_0^H \cdot R^{-1} \cdot w_0]^2$$



OOO Scenarios

Based on broadband ray-based simulation

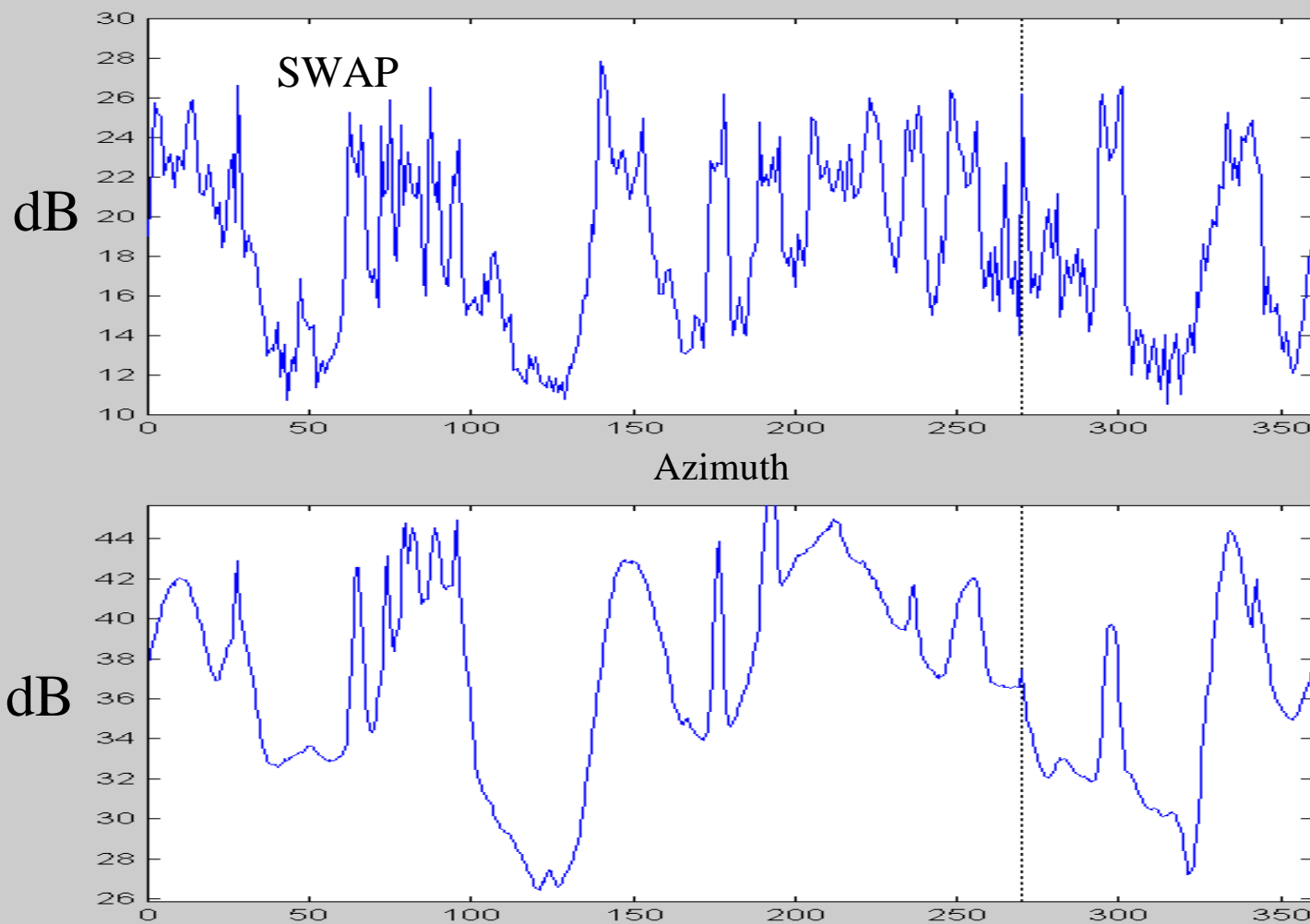


Continuous doppler by warping time series

Differential doppler on rays with different angles

140 dB Target

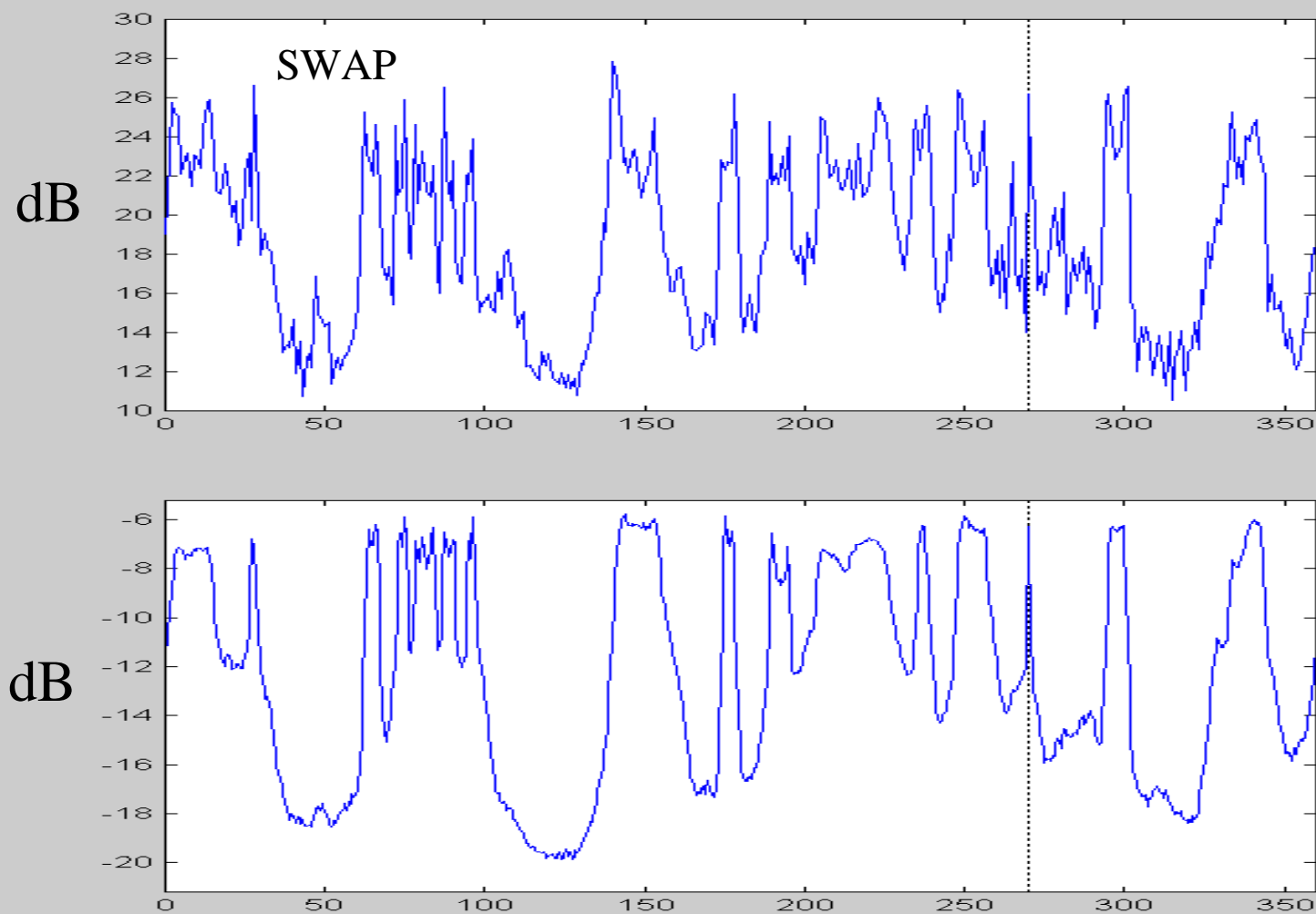
80 dB diagonal loading



Reduced rank, narrow band MVDR, 12 Hz average

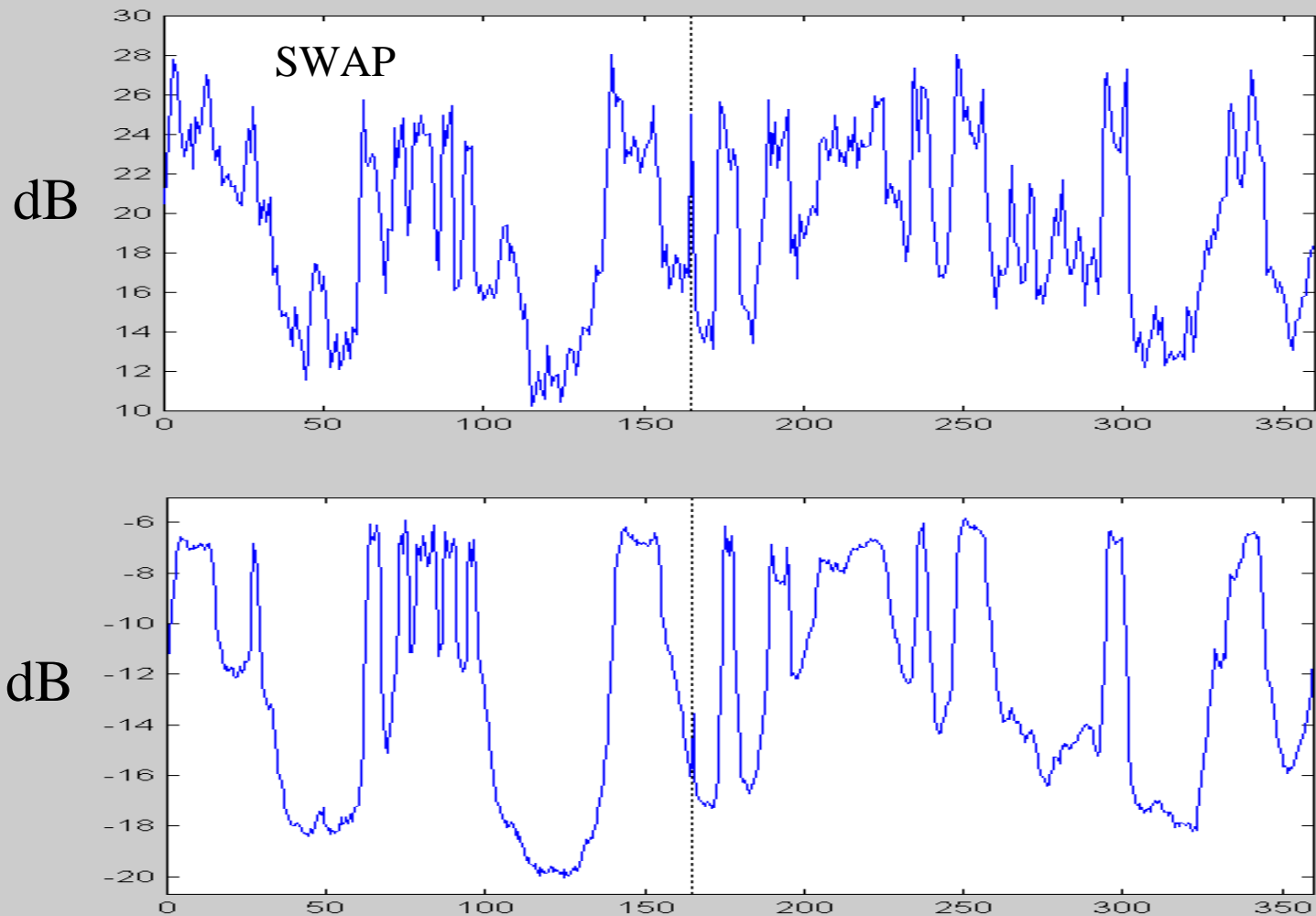
140 dB Target

30 dB diagonal loading



Reduced rank, narrow band MVDR, 12 Hz average

125 dB Target



Reduced rank, narrow band MVDR, 12 Hz average



Single Wavenumber Adaptive Processing

SWAP Improves ABF performance vs dynamics

- Increases exploitable degrees of freedom
 - Has extensions to matched-field processing
 - Has extensions to vertical apertures
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